Physics of Sound and Acoustics

Velocity of Sound in a Resonance Tube

Purpose:

To study the phenomenon of resonance in tubes and to measure the velocity of sound in air. This is accomplished by determining the wavelengths in air of different frequencies by producing standing waves in tubes.

Theory:

If a tuning fork is set in vibration and held over a tube (in our case an open-closed tube) compressions and rarefaction in the air travel down the tube and are reflected at the closed end of the tube. If the returning wave is in phase with those produced by the tuning fork when it returns to the fork, a condition of resonance exists and the loudness of the note from the tuning fork is greatly increase. In ideal conditions, this occurs when the length of the tube is close to an odd number of quarter wavelengths, that is,

(Fundamental mode of vibration or first harmonic)

$$l_1 = \frac{\lambda}{4},$$

(Second mode of vibration or third harmonic)

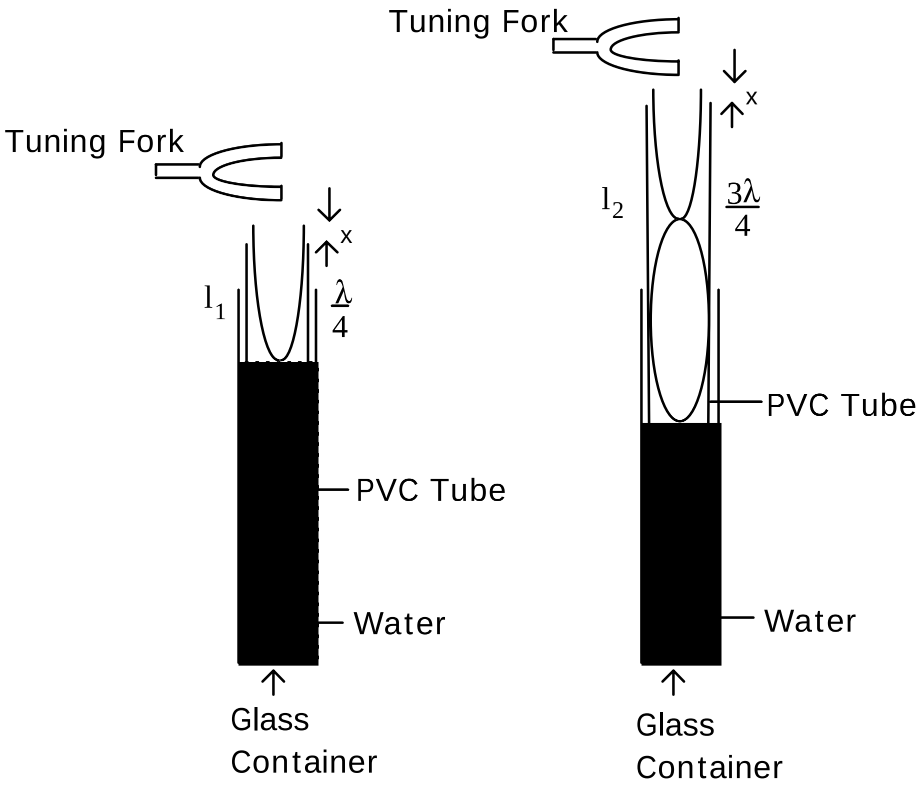
$$l_2 = \frac{3\lambda}{4}.$$

Experiments show, however, that the effective length of the tube is greater than the actual length by a constant amount x, known as the *end correction*. (See figure below). The position of the antinode at the open and of the tube is just outside the end of the tube. This extra distance x, up to a first approximation, is proportional to the diameter of the tube. Experimentally it is found that the end correction x is 0.3 times the diameter of the tube. Hence, instead of the equations above, we write:

$$l_1 + x = \frac{\lambda}{4}$$

and

$$l_2 + x = \frac{3\lambda}{4} .$$



By assuming that the end correction is constant, we can subtract the above equations and obtain:

$$l_2 - l_1 = \frac{\lambda}{2}$$

and the velocity of sound is established by the equation

$$v = \lambda f$$

which gives (f is the frequency of the tuning fork)

$$v = 2 f (l_2 - l_1) .$$

Procedure:

a) In the experiment, the length of the air column is adjusted by moving the resonance tube (PVC tube) up and down in a cylindrical glass container, as shown in the figure above.

b) The tuning fork with frequency f is made to vibrate by striking it with a rubber hammer and held above the tube. The tube is lowered and then raised until the first and second loud resonances are heard.

c) Measure l_1 and l_3, and repeat the procedure three more times and record the data. Find the velocity of sound.

d) Check your result by using the formula v = 331.7 + 0.61 T, where T is the room temperature in degrees Celsius.

e) First, find the end correction for the experiment from the formulas above. Second, measure the diameter D of the pipe and find the end correction by x = 0.3 D. Compare the values.

Note on the importance of end corrections:

The end correction x at the end of cylindrical pipe of diameter D is approximately 0.3 D. However, except for some organ pipes the bore of most wind instruments is not cylindrical and the open ends are flanged. In practice, the end corrections are somewhat larger than 0.3 D.

The end correction to be applied to the flue end of a pipe (flue organ pipes are usually made of wood and are square in cross section or circular if made of metal) has been found experimentally to be equal to the diameter of the tube. Thus the total end corrections are approximately D for closed cylindrical pipes and 1.3 D for open cylindrical pipes. For a square pipe of side a, the end correction is 2a for a stopped pipe, and 3a for an open pipe.

The correct relations for the frequency of open and closed pipes are:

<u>Open Flue Pipes</u>:

Cylindrical $f_n = n \frac{v}{2(L + 1.5D)}$

Square $f_n = n \frac{v}{2(L + 3a)}$

<u>Closed Flue Pipes</u>:

Cylindrical $f_n = (2n\ D1) \frac{v}{4(L + D}$

Square $f_n = (2n\ D1)\ \frac{v}{4(L + 2a}$

where v is the velocity of sound in the air, L is the length of the pipe from the mouth edge to the open end, D is the diameter of the pipe, a is the side length for square pipes, n is an integer number.